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CONTROL OF THE BLUE MOLD (DOWNY MILDEW) DISEASE OF TOBACCO BY SPRAYING[1]

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INTRODUCTION

Studies on the control of the blue mold or downy mildew disease, *Peronospora tabacina* Adam, by spraying were begun in 1932. Report of results has been delayed by the fact that the mild disease attacks of 1935 and 1936 did not provide a critical test of control measures. Spraying was suggested as a mold control when the disease first became destructive in this country. As a consequence, growers in South Carolina, North Carolina, and Virginia sprayed extensively with bordeaux mixture in 1932. Their results were poor. Later, Henderson (*3*)[2] reported promising preliminary results with calcium monosulphide. Armstrong and Sumner (*1*) found the colloidal copper superior to calcium monosulphide, and both better than cuprous

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[2] Italic numbers in parentheses refer to Literature Cited, p. 22.

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oxide. In Australia, Mandelson (*8*) reported very good results from spraying with colloidal copper and copper-soap, but McDonald (*6*) later reported failure to obtain satisfactory control by spraying. Blue mold is a very troublesome disease each year throughout the flue-cured area (Florida, Georgia, South Carolina, North Carolina, and Virginia) to which the present report applies more particularly, but it is extremely destructive only in occasional years, such as 1932 and 1937, and even then many localities escaped damage. Therefore, growers will be inclined to take a chance on escaping, unless a control measure can be provided that is relatively simple and inexpensive. The heat and gas methods of control have proved highly effective, but as yet neither is simple nor inexpensive, while the possibilities of producing tobaccos resistant to the disease are at present remote. For these reasons, efforts to develop a satisfactory spray treatment have been actively pushed. Spraying tobacco beds is inexpensive, but the big problem has been to find a spray treatment that is reasonably effective.

METHODS OF STUDY

Blue mold is very erratic in its behavior, so that if work were confined to the seedbed, and further, to one locality, it might be continued for years without decisive results. At Upper Marlboro, Md., experiments have been conducted each year beginning with 1932. During this entire time there has never been an extremely serious outbreak of blue mold. Also, the time that the disease is active at any one location is generally short, which again limits the extent of the studies that can be made. To overcome these difficulties, cooperative work has been conducted each year at Tifton, Ga.; Florence, S. C.; Oxford, N. C.; the Arlington Experiment Farm, Arlington, Va.; and Upper Marlboro, Md. In this way, continuous work was in progress from February 1 to June 15 and the results obtained in the extreme South were checked the same season at the more northern locations.

Work has been further facilitated by extensive tests in the greenhouse. Mold develops freely under greenhouse conditions, and much information can be obtained as to comparative effectiveness of different sprays (fig. 1). The use of glass slides coated with spray in which spores are germinated in drops of water has been recommended and is, doubtless, a valuable method with some diseases. It was discarded in work with this disease as the results appeared to be quite misleading.

How to measure results has been a major problem. In potato spraying, the yield is accepted, while with orchard crops the percentage of sound fruit is easy to determine. In early work, extensive leaf counts were made, grading them on the basis of tissue destroyed, but leaf conditions may change rapidly in a few days' time, and these records, on the whole, have not been satisfactory. Any practical evaluation must consider the yield and quality of plants, and so in later work, account has been taken (1) of plant mortality in the bed, (2) the yields of plants during the normal transplanting season for the district in question and the delay in transplanting, if any, because of the disease, and finally (3) the field stands secured.

SPRAYING RESULTS, 1932–36

Bordeaux mixture was widely used by growers in North Carolina and South Carolina during the 1932 epidemic with poor results. However, the fact that this spray is the standard control measure for very similar diseases of potatoes, cucumbers, and lima beans led to the belief that this failure might have been caused by improper usage. It was known that the majority of growers did not begin spraying until after the disease was present, and that they used poor equipment and applied excessive amounts. Reasoning along these lines, extensive experiments with bordeaux mixture were conducted in 1932, 1933, and 1934. Applications were made well in advance of the appearance of disease, different intervals between applications

FIGURE 1.—Effect of spraying twice weekly on blue mold in the greenhouse: *A*, Calcium monosulphide; *B*, cuprous oxide, rate of 2 pounds to 100 gallons plus 1 percent of cottonseed oil; *C*, an unsprayed check; *D*, Raleigh colloidal copper; *E*, cuprous oxide, rate of 1 pound to 100 gallons plus 1 percent of cottonseed oil. Note the superiority of the copper-oil sprays.

were studied, and various materials were added to the bordeaux. These included linseed oil, calcium arsenate, calcium caseinate, resin-soda sticker, bentonite, zinc sulphate, and molasses. Amounts of copper sulphate ranging from 1 to 8 pounds per 50 gallons of water were tested, as well as different proportions of copper sulphate and lime. Results showed that outstanding blue mold control was obtained in some instances. These positive results were obtained, however, when the disease attack was short and not severe. When conditions favorable for blue mold prevailed for any considerable period, the bordeaux sprays delayed disease development 5 to 7 days, after which sprayed plots went down before the disease just as severely as had the unsprayed a few days earlier. In fact, in some experiments it appeared that leaves coated with bordeaux died more rapidly than unsprayed leaves, once they became infected. In addition, it was observed that while the bordeaux-sprayed plants usually lived and grew well after transplanting, this was not always true. In some tests

the stands were poorer and growth was less vigorous. In 1933 in an experiment involving three beds (a check, one sprayed with bordeaux mixture, and one with calcium monosulphide) successive field plantings were made on June 1, 5, and 9. The June 1 pulling of plants was made just prior to applying the last spray. A general and moderately severe attack of mold developed on June 2. Recovery from this began June 5 and was well advanced by June 9. Results are shown in table 1.

TABLE 1.—*Effect of bordeaux mixture and calcium monosulphide sprays on field stands at Upper Marlboro, Md., 1933*

Spray treatment	Loss in stand by June 20 with plants set—			Loss in stand by July 17 with plants set—			Average weight of tops on July 25 with plants set—		
	June 1	June 5	June 9	June 1	June 5	June 9	June 1	June 5	June 9
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Pounds*	*Pounds*	*Pounds*
None	8.8	5.6	2.4	8.8	6.4	6.4	1.02	0.96	0.62
Calcium monosulphide	3.2	12.9	2.4	11.2	18.5	12.9	.91	.87	.64
Bordeaux mixture	10.4	10.4	6.4	10.4	21.7	10.4	.92	.82	.61

The stand counts given were obtained from plots of 124 plants each, and the weights were the averages of 40 plants. It is noteworthy that the sprayed plants, and particularly those treated with bordeaux, did not live as well as the unsprayed. Furthermore, the growth was uneven, with many plants stunted, and this difference is reflected in the reduced weights of sprayed plants. At the time of setting, all the sprayed plants appeared superior to the unsprayed, so these results could not have been anticipated. However, similar results have been obtained a number of times.

The fact that bordeaux sprays failed to control the disease under severe conditions, that once infection developed, sprayed plants were affected as severely or more so than the unsprayed, and that poorer field stands and reduced growth might result, pointed to the conclusion that some other type of fungicide must be found. Search for this led to the testing of a wide variety of mixtures. In these studies the maximum concentration tolerated by the plant was determined and then the disease-control value. Tests were made in the greenhouse and in seedbeds. The following materials were tested.

Sprays

Copper-soap
Copper sulphate
Basic copper sulphate
Basic copper acetate
Neutral copper acetate
Ammoniacal copper carbonate
Copper stearate
Copper silicate
Copper-naphthol
Palustrex sulphonate B
Burgundy mixture
Copper phosphate
Copper(ous) oxide
Copper resinate
Copper zeolite
Raleigh colloidal copper
Saanichton spray
Colloidal sulphur
Lime sulphur
Calcium monosulphide
Ethyl mercury phosphate
Calomel
Sodium sulphonate
Oxyquinoline sulphate
Potassium sulphide
Sodium hydroxide
Sodium bicarbonate
Laundry soap
Fish-oil soap
Cottonseed-oil emulsion
Mineral-oil emulsion

Dusts

Copper carbonate
Copper stearate
Copper-lime
Bordeaux
Copper resinate
Calotex
Phenol mercury
Sulphur
Wood ashes

The data collected in testing all these materials are extensive and only the conclusions will be given.

Various copper and sulphur sprays gave the best control, and, in general, the former were distinctly the more effective. The best sulphur spray was calcium monosulphide (6½ pounds to 50 gallons of solution). The best copper sprays were Raleigh colloidal copper (1½ to 2 pounds of copper sulphate to 50 gallons of water) and copper-soap (1 pound copper sulphate, 5 pounds soap to 50 gallons of water). Sprays were superior to dusts. In 1934 and 1935, these better sprays were thoroughly tested, and excellent mold control was obtained in some instances. However, while their superiority to bordeaux was clearly shown, it did not appear that any were consistently effective.

Prior to this time, a number of combination sprays and dusts had been tested, including various combinations of copper and sulphur, but results were not good. In 1933, however, it was found that a 1-percent cottonseed-oil emulsion had fungicidal value against blue mold, and the oil-sprayed plants did not wilt as easily as those sprayed with bordeaux. Consequently, it was decided to test copper-oil combinations. Work on a small scale was conducted in seedbeds at Arlington Experiment Farm, Arlington, Va., and at Upper Marlboro, Md., in 1934, the colloidal copper and emulsified cottonseed oil being combined. These studies were continued that year in the greenhouse, and in both seedbed and greenhouse the combination showed promise. Repeated tests showed that the combined spray was much superior to the copper alone. For example, in one test, with the copper alone, 49 percent of the plants survived; with copper plus soap, 76 percent; and with copper plus oil emulsion, 97 percent. The oil was tried in combination with bordeaux but results were not so favorable. However, a combination of red copper oxide and oil gave results almost equal to those secured with the colloidal copper-oil. The colloidal copper is difficult to prepare and not available commercially, so the copper oxide-oil was used in most of the seedbed tests that followed. This combination was used in a large series of beds at Upper Marlboro, Md., in 1935, which constituted the first large-scale test of this spray combination. Mold control was excellent, but the disease, although general in the unsprayed checks, was not severe. The cooperating growers, however, were very enthusiastic because the transplanted plants lived and grew exceptionally well.

In 1936, the copper-oil spray was thoroughly tested at Tifton, Ga.; Florence, S. C.; Oxford, N. C.; Arlington Farm, Va.; and Upper Marlboro, Md. The results were good, but some mold developed in many of the sprayed beds, although in no case did it cause any damage or delay. Mold attack in 1936 was generally light, although transplanting was delayed 7 to 16 days in some areas. Transplant-

ing experiments gave uniformly good stands from the sprayed beds and, in a few cases, poor stands were obtained from check beds.

However, while conclusive results were not obtained in 1935 or 1936, a large amount of work was conducted with the result that when the spring of 1937 approached, a definite and detailed spray program was ready for test.

SPRAYING RESULTS IN 1937

The results of 1936 were encouraging, but how the spraying would hold up with a severe disease attack still remained a question. The fact that mold was not eliminated, plus the unfavorable earlier results with bordeaux and other mixtures, prevented undue optimism. Consequently, when it appeared that 1937 was likely to provide the severe test needed, plans were made to gather a sufficient body of data to make possible definite conclusions. The usual small experiments with different sprays were conducted, but the major effort was to try out the copper oxide-oil spray under a wide variety of conditions. The spray formula used was red copper oxide one-half or three-quarters of a pound, Lethane spreader 1 quart, cottonseed oil one-half gallon and water to bring the volume to 50 gallons. Applications of spray were made twice weekly. In general, entire beds were sprayed, and other adjacent unsprayed beds considered as checks. Of course, no two beds are exactly alike, but, where any difference was apparent, the poorest bed was selected to be sprayed. The spraying was done by a number of different persons, some of whom had had no previous spraying experience. The severity of the disease outbreak was different in the various localities. In some cases, spraying was begun well in advance of the disease outbreak; in others, beds were infected at the time spraying was initiated. Obviously, such matters as bed fertilization, date of planting, location of beds, thickness of stands and all cultural practices varied widely. Since the object was to determine the value of this spray control in practical terms, particular attention was given to obtaining results that would measure (1) protection of seedbed stands, (2) protection against transplanting delays, and (3) protection of field stands. Cooperating growers were asked to keep a record of time and number of plants set, but they followed their own desires as to when and how they were set.

GRANVILLE COUNTY, N. C.

Mold was first observed in Granville County, N. C., on April 16, which was about 2 weeks earlier than usual. The disease was general throughout the district by April 30, and recovery took place during the period May 10 to 18. In most beds, damage was limited to severe defoliation and resulting transplanting delays. Spraying was begun April 12, and 10 applications were made. Copper oxide was used at the ½-pound-per-50-gallon rate for the first five applications, and at the ¾-pound rate for the remainder. At the Tobacco Branch Station, Oxford, N. C., the early applications were made through the covers and, except for a tendency to overspray, results were entirely satisfactory. Amounts applied per 100 square yards of bed ranged from 2.3 to 5.4 gallons. Effective control was obtained in all sprayed beds. Some mold developed, but in no case did it cause defoliation or

delay transplanting. Table 2 gives the yield from sprayed and check beds at four cooperative locations. At the tobacco station, a large bed was sprayed with practically perfect disease control, but no unsprayed check of adequate size was available for plant yield comparisons.

TABLE 2.—*Blue mold spraying results in Granville County, N. C., 1937*

Cooperator	Original plants per square yard	Plants transplanted per square yard of bed			
		Pulled by May 13		Total from all pullings	
		Sprayed	Not sprayed	Sprayed	Not sprayed
	Number	*Number*	*Number*	*Number*	*Number*
Casper P. Critcher	342	9	0	77	33
Frank P. Sherman	657	25	0	269	50
Willie H. Newton	639	100	75	300	180
James T. Yancey	279	15	0	50	35
Average	479.2	37.2	18.7	174	74.5

Field plantings showed no differences in stand between sprayed and unsprayed plants.

Despite the fact that the disease killed practically no plants, it may be seen from the figures on total plants that whereas 3.2 acres were set per 100 square yards of sprayed bed, only 1.4 acres were set from similar unsprayed areas. Approximately 5,500 plants are required to set 1 acre. The original plant stand counts also point to the desirability of good initial stands if a large yield of plants is to be expected. At Oxford, plants were protected from mold by benzol gas treatment as well as by spraying. The gas method completely eliminates the disease while the spray treatment does not, but close comparisons failed to show any practical differences, considering number, earliness, or quality of plants. The normal transplanting season for this district is May 1 to 20.

WILSON COUNTY, N. C.

Mold was first observed in Wilson County, N. C., on March 25, which was 10 to 15 days earlier than usual. Infection became general throughout the district by April 16. There were two periods of marked activity, April 13 to 15 and April 23 to 24. Recovery occurred the first week in May and the bulk of the crop was set the week of May 10. The normal transplanting period for this district is April 25 to May 15. The first spray was applied in the main series on March 25, and 14 applications were made. For four of the applications (Nos. 9–12), copper oxide was used at the rate of three-fourths of a pound to 50 gallons of water, and for the remainder the regular ½-pound rate was used. The last two applications were made after the disease had become inactive, and omission of these applications from some beds indicated that they were not needed.

The data in table 3 cover the period to May 15, which is the end of the normal transplanting season for the area.

TABLE 3.—*Blue mold spraying results in Wilson County, N. C., 1937*

Cooperator	Bed area		Total plants transplanted		Plants transplanted per square yard of bed		Field stand	
	Sprayed	Not sprayed	Sprayed	Not sprayed	Sprayed	Not sprayed	Sprayed	Not sprayed
	Square yards	*Square yards*	*Number*	*Number*	*Number*	*Number*	*Percent*	*Percent*
B. J. Dew	150	115	34,130	15,125	227	131	97	95
Chas. Dew	280	280	33,000	4,250	118	15	99	91
A. D. Williams	90	190	9,100	15,000	101	79	99	97
W. C. Thompson	150	150	17,875	5,500	119	37	97	91
F. W. Boswell	200	200	27,650	18,000	138	90	99	79
Arvin Nicholas	80	90	7,810	6,840	98	76	98	97
Simple average	158.3	170.8	21,594	10,786	133.5	71.3	98.1	91.7

SPRAYING AFTER MOLD APPEARANCE

At two Wilson County locations, seedbeds were sprayed beginning April 15, at which time spots of mold infection were present in both locations. Mold was not active for the following 10 days; consequently, four spray applications had been made prior to the April 25 outbreak. Transplanting results showed that at one location 157 plants per square yard were obtained from the sprayed area and 131.5 from the unsprayed; at the other location the figures were: Sprayed, 127; and unsprayed, 37. Although these results were not equal to those obtained in adjoining seedbed areas where spraying was begun sooner, nevertheless, the fact that benefits from spraying could be secured under such conditions is of much importance, as many growers would be expected to follow similar practices.

Further tests of this same sort were conducted at two locations in Wake County, N. C. The mold was present in spots at the time the first application was made (April 16), but there was time for three to four treatments prior to the general outbreak (April 23), and the results secured were very good (table 4). The total number of applications was eight.

TABLE 4.—*Blue mold spraying results in Wake County, N. C., 1937*

Cooperator	Bed area		Total plants transplanted [1]		Plants transplanted per square yard of bed		Field stand	
	Sprayed	Not sprayed	Sprayed	Not sprayed	Sprayed	Not sprayed	Sprayed	Not sprayed
	Square yards	*Square yards*	*Number*	*Number*	*Number*	*Number*	*Percent*	*Percent*
Leslie Rand	50	50	8,075	2,540	161.5	51	99.5	[2] 71
Harvey Johnson	50	150	5,210	6,380	104	42.5	97.5 98.5	[3] 98.5 100

[1] Through May 11. [2] Apr. 30 setting. [3] May 6 setting.

The behavior of all sprayed beds was the same. The development of the disease was greatly delayed, after which all went through a mild disease attack. This was characterized by a slight yellowing of the

leaves, plus small lesions, but few leaves were killed and no plants, as far as could be observed. Disease symptoms disappeared completely in 3 to 4 days, and no further indications of infection were seen. Plants never stopped growing, and it was the unanimous opinion of the growers that there was no transplanting delay. On the other hand, the unsprayed beds were severely defoliated, about 20 percent of the plants killed, and transplanting was delayed about 2 weeks. Field counts showed from 97 to 99.5 percent stand with sprayed plants and 71 to 100 percent with unsprayed. The greater certainty of obtaining a good stand with sprayed plants will be pointed out later (p. 10). Stimulation of growth was observed in certain Wilson County sprayed beds (fig. 2).

FIGURE 2.—(*A*) Sprayed and (*B*) unsprayed plants on a farm in Wilson County, N. C. In addition to blue mold control the spray treatment produced marked stimulation. Note that the bent sticks, which supported the cotton cover, are plainly visible in the unsprayed bed but practically concealed by the heavy growth of plants in the sprayed bed. The stand of plants in the unsprayed bed was reduced about 22 percent by the blue mold. The sprayed bed set 11,920 plants per 100 square yards during the normal transplanting season and the unsprayed bed 3,660.

In the eastern North Carolina district, some growers obtained information as to the spray program and treated their beds independently. These locations were carefully checked, and good results were reported except in one case where the final application caused injury. In this instance, it was found that the sprayer had been used to apply an oil spray to poultry houses and had not been cleaned out before making the tobacco-bed application.

COLUMBUS AND ROBESON COUNTIES, N. C.

The tests in Columbus and Robeson Counties, N. C., constitute a very interesting experiment in that they were undertaken to find whether spraying would be profitable after mold was generally distributed through a district. The work was conducted in cooperation with the North Carolina Extension Service. The experimental beds were selected on March 19, at which time many beds in the district were already showing mold damage. Only beds that showed no evi-

dence of disease were chosen, but at the time the first spray application was made (March 22) several of the beds selected had developed evident symptoms, and others were substituted. Later disease developments indicated that all beds were probably infected at the start, but since there was no general disease outbreak until April 7, four applications of spray were made prior to this time. All beds were sprayed on a fixed schedule, and it was not possible to delay applications. As a consequence, several treatments were made during showery weather, which prevented thorough work. Copper oxide at the rate of one-half pound to 50 gallons of water was used throughout and a total of 10 sprays were applied. The last two were made after the disease had passed its peak and omission of these applications from some beds showed they were not needed. Active mold development in the sprayed beds was limited to the period April 15 to 19. This attack terminated as suddenly as it began, and actually caused little damage. So far as could be determined, no plants were killed in sprayed beds, while in the unsprayed the kill was estimated at 30 percent. Transplanting delays were very slight in sprayed beds, and around 2 weeks in unsprayed beds. The growers kept records of the time and number of plants set. On April 28, these data were collected and counts made of field stands (table 5). The normal transplanting season for Columbus County is April 1 to 20, and for Robeson County, April 10 to 30.

TABLE 5.—*Blue mold spraying results in Columbus and Robeson Counties, N. C., 1937*

Cooperator	Seedbed area		Plants per square yard of bed of transplanting size on Apr. 28		Plants per square yard of bed set into the field prior to Apr. 28		Field stand	
	Sprayed	Not sprayed	Sprayed	Not sprayed	Sprayed	Not sprayed	Sprayed	Not sprayed
	Square yards	*Square yards*	*Number*	*Number*	*Number*	*Number*	*Percent*	*Percent*
W. S. Britt	75	285	93	52	40	3	99	47
R. Bridgman	100	100	81	76	55	5	99	87
S. F. Caldwell	125	125	144	81	383	6	83 72	72 21
Luther West	100	100	99	36	55	27	95	95
Shelton West	100	165	90	54	110	16	99	
W. P. Rabon	100	500	93	45	85	11	98	98
L. B. Nance	90	150	18	18	153	11	99	99
W. M. Hooks	150	150	102	49	43	9	97	97
J. W. Wilson	200	1,000	85	72				
W. G. Prevatt	100	200	75	49				
Average	114	277.5	88.0	53.2	115.5	11	93.4	77

The gains from spraying that were secured are so outstanding that the figures given in table 5 require no comment. However, there were developments of interest with regard to field stand, and thick and thin bed stands. At the W. S. Britt location, the plants were extremely thick in the bed, and the grower intended to thin but failed to do so. Despite the dense plant growth, spraying gave good results, and the disease did no more damage than in beds with very thin stands. A field planting was made from this bed at a time when the sprayed portion showed maximum mold development. These plants gave a field stand of 99 percent, while plants from the unsprayed check set the same time gave a field stand of 47 percent.

The wide variation in number of plants set from different beds is to be noted in the table, and the major reason for these differences was the initial bed stand. Assuming that about one plant per square inch could be produced, the initial counts showed a close approximation of this at the S. F. Caldwell location. The average at this location was 122 per square foot in the sprayed bed, and 120 in the unsprayed bed. By April 28, five pullings had been made from the sprayed bed. Adding to this the number in the bed large enough to be set, it is seen that 100 square yards would transplant 9.6 acres, since approximately 5,500 plants are required to set one acre. From the similar unsprayed bed, one pulling had been made and this plus the large plants in the bed would set at the rate of 1.6 acres per 100 square yards. On the other hand, at the L. B. Nance location, the initial plant stands were: Sprayed bed, 24 plants per square foot, and unsprayed, 20. Two pullings removed practically all plants from the sprayed bed and set at the rate of 2.8 acres per 100 square yards. From the unsprayed bed one pulling was secured which set one-fifth acre per 100 square yards. It may be noted that field-stand counts at the Caldwell location were low, but this was because they were secured from several very early plantings.

Considering the wide range from very thin to very thick stands that was provided in this experiment, there was no indication that thin stands were desirable from the point of mold control or that better spraying results were obtained with thin stands. Attention is drawn to this development, because it was thought likely that such differences would be found.

SOUTH CAROLINA

About 3,000 square yards of bed were sprayed at various locations in South Carolina, and at most of these the mold was quite severe. Copper oxide was used at the rate of one-half pound per 50 gallons of water throughout. Applications were generally made twice weekly, but because of a crowded spray schedule, some applications were made under unfavorable conditions because of rain, and some were skipped entirely. The total number of treatments ranged from 5 to 16. The behavior of sprayed beds was quite uniform. During a period of 10 days to 2 weeks after mold had become severe in the check beds, the sprayed beds showed very little disease. Then, during the period April 16 to 20, they underwent a moderate disease attack. The recovery from this was rapid and few to none of the plants were killed, nor were the plants appreciably delayed. In contrast, the unsprayed beds had, in many instances, 50 percent or more of the plants killed and planting was delayed 2 to 3 weeks. To check on the influence of mold on sprayed plants, several of the cooperators made large plantings from sprayed beds at the time when mold was at its maximum and practically perfect stands were obtained. Field stands throughout the district were generally good. Definite data as to plant yields were not taken, but the following notes indicate the trend.

L. M. Lawson, Darlington.—Three pullings were made from the sprayed bed before any were available in the check. The bulk of the crop was set from the sprayed bed.

J. S. Howle, Darlington.—The yield of plants at the time more than half the crop was set was 2 to 1 in favor of the sprayed bed.

Lynn Lee, Timmonsville.—About 50 percent of the plants were killed in the check and very few in the sprayed bed. Spraying was begun after the disease had appeared but before it had become general, and only five applications were made.

J. S. Neal, Mullins.—From 35 to 40 percent of the plants were killed in the check bed and, so far as could be determined, none in the sprayed bed. Four large pullings were made from the sprayed bed, while one small pulling was being obtained from the check.

G. M. Brown, Mullins.—Mold killed many plants in the check bed and few, if any, in the sprayed. Most of the crop was set from the sprayed bed.

Experiment station, Loris.—There was a considerable kill of plants in the check bed and few, if any, were killed in the sprayed.

C. B. and R. W. Smith, Loris.—Same as at the experiment station, Loris.

C. B. and R. W. Smith, Florence.—The disease did no damage at this location.

Experiment station, Florence.—Some plants were killed in the unsprayed bed and in a series of sprayed beds no plants were killed except in one small spot.

George Wiles, Hartsville.—There was rather marked growth stimulation in the sprayed bed, but the disease did no appreciable damage to either sprayed or unsprayed plants.

In addition to these experimental beds, one large grower sprayed a series of beds and reported good results.

GEORGIA

The 1937 blue mold outbreak in Georgia was the most destructive that has yet occurred in this country. Throughout the main tobacco belt, fully 80 percent of the plants were killed and the remainder were so weakened that transplanting was delayed 4 to 5 weeks. The disease was very active over a period of more than 2 months and the number of sprays applied was necessarily large. It ranged from 11 to 23 in different beds. Late applications were omitted from some beds, and in this way it was determined that applications made after recovery had occurred were unnecessary. Consequently, it appears that even under these severe conditions, a maximum of 15 applications was adequate. Copper oxide was used at the rate of one-half pound per 50 gallons of water throughout.

The Georgia results were of particular importance in that they seem to answer a frequent question, namely, how effective would the spray method of blue mold control be, provided cool weather and favorable mold conditions were prolonged? Pertinent data regarding disease development in relation to spraying are summarized in table 6.

Study of these figures shows that the disease appeared in unsprayed beds about February 14 and in the sprayed ones approximately 10 days later. The average date of maximum disease development in the check beds was March 3 and in the sprayed, March 20. It was 17 days before the unsprayed beds showed signs of recovery and only 3½ days before recovery was evident in the sprayed beds. And finally the disease killed 6 percent of the sprayed plants and 80 percent of the unsprayed plants. These last two sets of figures point to the real basis for the outstanding gains obtained from spraying; namely, reduced disease development, which results (1) in little or no transplanting delay and (2) in low plant mortality.

TABLE 6.—*Record of disease development of sprayed and unsprayed beds, Tift County, Ga., 1937*

Cooperator	Date of disease appearance		Date of maximum disease development		Date recovery began		Interval between maximum disease and beginning of recovery		Plants killed	
	Sprayed	Not sprayed	Sprayed	Not sprayed	Sprayed	Not sprayed	Sprayed	Not sprayed	Sprayed	Not sprayed
							Days	*Days*	*Per-cent*	*Per-cent*
L. M. Veasey	Feb. 12	Feb. 8	Mar. 19	Mar. 10	Mar. 23	Mar. 20	4	10	0	84
E. Hutchinson	Mar. 4	Feb. 22	Mar. 22	Mar. 1	Mar. 24	Mar. 15	2	14	3	78
R. H. Hutchinson[1]	Feb. 22	do	Mar. 16	Mar. 16	Mar. 20	Apr. 4	4	19	16	94
J. G. Whigham	do	do	Mar. 12	Mar. 8	Mar. 16	Mar. 22	4	14	1	85
G. Drexler[2]	Mar. 22	Feb. 4	Apr. 12	Feb. 20	Apr. 16	Mar. 16	4	24	2	81
J. T. Skinner[3]	Mar. 1	Feb. 14	Mar. 8	Feb. 22	Mar. 12	do	4	22	16	90
Experiment station	Feb. 2	Feb. 7	Mar. 22	do	Mar. 24	do	2	22	4	51
Average	Feb. 24	Feb. 14	Mar. 20	Mar. 2	Mar. 24	Mar. 20	3.4	17.9	6.0	[4]80.4

[1] 1 end of sprayed bed was shaded and very wet.
[2] This sprayed bed was sown 1 month after the check and also after mold had developed in the check bed.
[3] This sprayed bed was sown 2 weeks after the check. Blue mold present at time spraying was begun.
[4] Some plants died in the check beds after these final counts were made.

However, it is possible also to measure this reduction in amount of disease directly by means of leaf counts. This has been done many times, and one set of such data follows. These figures were secured by pulling random lots of 25 plants each and classifying the leaves as to disease damage. Since counts taken at one time would find the disease at different stages of development in different beds, the following counts were made in each case at the time that the disease was at its maximum in that particular bed (table 7).

TABLE 7.—*Amount of infection at time of maximum mold development, Tift County, Ga., 1937*

Cooperator	Leaf counts of plants sprayed				Leaf counts of plants not sprayed			
	Healthy	Slightly diseased	Severely diseased	Dead	Healthy	Slightly diseased	Severely diseased	Dead
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
L. M. Veasey	121	22	9	5	0	4	8	104
E. Hutchinson	108	8	9	25	0	4	7	95
J. G. Whigham	91	19	19	13	0	3	4	107
G. Drexler	82	19	25	19	1	6	11	89
J. T. Skinner	74	10	11	51	0	4	12	100
Experiment station	90	39	30	11	0	6	8	97
Average	94.3	19.5	17.2	20.7	0.17	4.5	8.3	98.7

These figures show that when the disease was at its worst, the majority of the sprayed plant leaves still appeared healthy, while practically no leaves were healthy in the check bed. The high number of dead leaves in the latter merely indicates that these plants were largely defoliated.

The time plants are available for transplanting and the total plant yields, however, are the important measures of blue mold control,

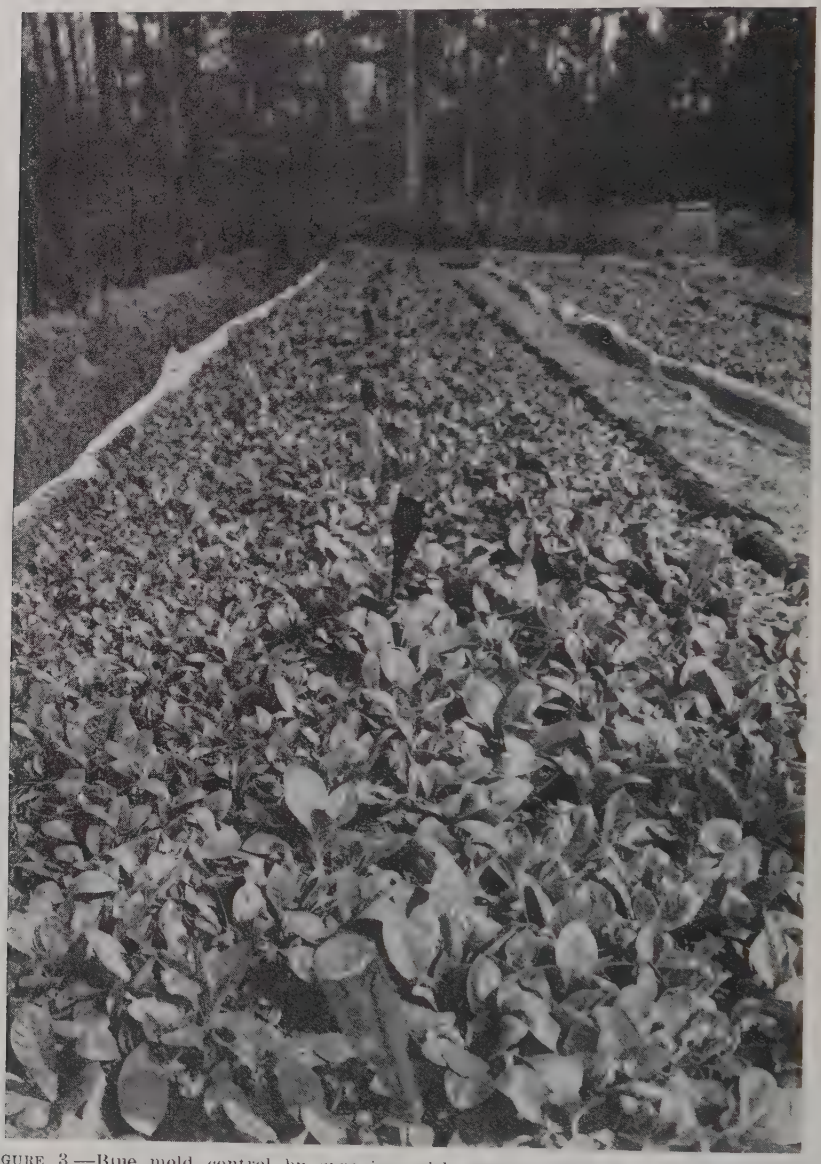

FIGURE 3.—Blue mold control by spraying with copper oxide-oil under severe disease conditions. This bed was located near Tifton, Ga. Ten acres were set from the 180 square yards of sprayed bed, and of this 6 acres were set prior to April 1, the normal planting season for this area being March 25 to April 15. Photographed March 18, 1937.

and, because of the critical test provided in the Georgia experiments, these figures are presented in some detail. The normal planting season for the district is March 25 to April 15.

Figures 3 and 4 show the condition of typical sprayed and check beds in these experiments. Under these very severe disease conditions, the growers were able to set very few plants from their unsprayed beds by the end of the normal planting season, April 15, while from the sprayed beds an average of 3 acres was set per 100 square yards. This

FIGURE 4.—The destructive effects of blue mold in the unsprayed check beds on the same farm as that represented in figure 3. Only four-fifths of an acre was set from this 180-square-yard bed and nothing prior to April 1. Photographed March 18, 1907.

is just about the same as was set from sprayed beds in other sections and is further verification of the general conclusion by all concerned that spraying practically eliminated blue mold damage, despite the prolonged and destructive attack. Because of the extreme scarcity of plants, Georgia growers continued transplanting from their unsprayed beds much later than usual, so in order to make the records more complete final data on plants set were not taken until May 10 (table 8).

TABLE 8.—*Acreage of tobacco set from sprayed and unsprayed beds in Tift County, Ga., 1937*

Cooperator	Total area		Total acreage set before—						Acreage set per 100 square yards of seedbed before—					
			Apr. 1		Apr. 15		May 10		Apr. 1		Apr. 15		May 10	
	Sprayed	Check	Sprayed	Check	Sprayed	Check	Sprayed	Check	Sprayed	Check	Sprayed	Check	Sprayed	Check
	Square yards	*Square yards*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
L. M. Veazey	300	1,600	6.0	0.0	9.0	1.0	22	27.0	2.0	0.0	3.0	0.06	7.3	1.7
E. Hutchinson	160	180	3.0	.0	6.0	.5	10	3.0	1.9	.0	3.75	.3	6.3	1.7
R. H. Hutchinson	180	100	1.5	.0	3.0	.0	8	.0	.8	.0	1.7	.0	4.4	.0
J. G. Whigham	180	180	6.0	.0	7.5	.5	10	.8	3.3	.0	4.2	.28	5.5	.44
Experiment station	1,200	100	20.0	.0	36.0	.3	60	1.8	1.7	.0	3.0	.3	5.0	1.8
G. Dreyler	[1] 100	200					4.0	1.5					4.0	.75
J. T. Skinner	225	200	1.0	.0	6.0	.0	9.0	1.0	.4	.0	2.7	.0	4.0	.5
Total	2,345	2,560	37.5	.0	67.5	2.3	123.0	35.1	10.1	.0	18.35	.94	36.5	6.89
Average	335	366	6.3	.0	11.3	.38	17.6	5.0	1.7	.0	3.1	.16	5.2	.98

[1] This sprayed bed sown 6 weeks after the check.

In addition to the regular tests, four beds were sprayed, starting very late when the disease had become general throughout the district. These beds developed general infection after one to two spray applications had been made, and no control whatever was obtained. These results are in line with others and indicate that good results may be obtained when spraying is begun late, provided the disease develops slowly so that three to four applications are made prior to a general outbreak.

DISCUSSION

It is quite surprising that the copper oxide-cottonseed oil spray should give so much better blue mold control than any of the many copper sprays used alone. Red copper (cuprous) oxide was first developed by Horsfall (*4*) as a seed treatment, and when used as a spray it did not give good blue mold control. Cottonseed oil was reported by Martin and Salman (*9*) to have fungicidal value. This report was confirmed with respect to blue mold in 1933, and preliminary tests with the combination of copper and oil were conducted in 1934. Large-scale tests were initiated in 1935 and results were excellent. These tests were continued in 1936 with similar results, but in none of these years was the disease highly destructive. Consequently, there was good reason to doubt the effectiveness of this treatment under severe disease conditions. Therefore, it seemed of the utmost importance to test this mixture extensively and under as severe conditions as possible before proceeding further.

EFFECTIVENESS OF SPRAYING IN REDUCING DIFFERENT TYPES OF BLUE MOLD INJURY

For purposes of evaluation, blue mold injury was considered in terms of (1) plant mortality in the seedbeds, (2) transplanting delays, and (3) field stands obtained. Inspection of the data obtained during the 1937 epidemic shows that the maximum kill of plants in any sprayed bed was 16 percent (table 6), and in this instance practically all the plants in the unsprayed check were killed. The disease was extremely destructive throughout the Georgia tobacco belt and the average kill of plants in the unsprayed beds of this district was 80 percent, while the average kill for all sprayed beds was 6 percent. In other localities, up to 50 percent of the plants were lost in unsprayed beds, while in those sprayed there was practically no loss. Finally, it may be noted that even the few plants killed in sprayed beds represented no real loss as they were invariably small, weak individuals. A safe estimate would rate spraying as at least 90-percent effective in protecting plant bed stands, on the basis of results to date.

The second phase of blue mold injury results from the severe defoliation which retards growth and hence delays transplanting. Spraying did not eliminate the mold, and how much the mild attacks that occurred in sprayed beds actually delayed the plants is difficult to estimate. Growers who followed the work very closely were generally of the opinion that the plants were not delayed at all, pointing out that growth never ceased and the roots always remained white and healthy. Certainly an estimate of 3 to 4 days' delay for the average of sprayed beds would be liberal, and on the basis of an average delay

of 3 weeks for unsprayed beds it may be concluded that the spray treatment reduced transplanting delays by 80 to 85 percent. The fact that sprayed beds in the different districts averaged 2½ to 3½ field acres per 100 square yards during the normal transplanting season, while the unsprayed checks set from 0 to 1⅓ acres, is practical evidence that transplanting delays were largely eliminated. Much emphasis is placed on the gains in plants set out during the normal transplanting season, as the result of spraying. By far the most universal loss caused by this disease is transplanting delay, and, as is well known, crops that are set out late do not generally yield as well as those set out at the proper season.

The third type of blue mold loss is the poor field stands that may result from diseased plants. Since sprayed beds show some mold infection, it might follow that this would occasionally result in poor stands. For 3 years, however, field stands from sprayed and unsprayed beds have been studied intensively, and all evidence points to the conclusion that the mold present in these sprayed beds has represented no field hazard. In the 1937 experiments, plantings were purposely made from sprayed beds at a time when these were showing a maximum of infection, and practically perfect stands of vigorous plants were secured. On the other hand, despite the fact that growers planned to allow plants to recover before transplanting, they occasionally obtained poor stands with the unsprayed plants. Hence, the results indicate that spraying gives perfect protection against the loss of plants following transplanting due to blue mold infection.

Considering all three aspects of blue mold injury, it seems safe to say that spraying has reduced mold damage by 85 to 90 percent.

MECHANICS OF SPRAY PROTECTION

To consider the mechanics of spray protection it will be necessary to trace briefly the essential differences in disease development in sprayed and unsprayed beds. The appearance of the disease in sprayed beds is generally but not always delayed, while the development of the disease is always much retarded. With mild attacks, as in 1936, very little mold was seen in sprayed beds prior to transplanting. With severe conditions, however, as in 1937, about 2 weeks after the unsprayed beds had become badly affected, the sprayed beds suffered a mild attack. Other sprays, such as bordeaux, have retarded disease appearance and the important gain from the copper oxide-oil has been the minimized attack after the disease develops. This minimized attack is apparently because of increased plant resistance, as indicated by slower progress of the disease in infected leaves, the short interval between peak development and recovery, and the generally reduced effect on the plants. Increasing plant resistance by spraying is a new development that will need further study. That sprays applied to leaf surfaces may exercise internal effects is known. Wilson and Runnels (*10*) have shown that bordeaux mixture and other copper sprays increase cuticular transpiration. Krausche and Gilbert (*5*) conclude that this is owing to the absorption of copper, which changes the permeability of cell membranes. De Long (*2*) has found that copper sprays control the potato leafhopper through internal leaf effects, while Mader and Blodgett (*7*) showed that spraying potato leaves with bordeaux may

greatly reduce scab infection on the tubers. In each case, the obvious suggestion that the results were due to a direct action of absorbed copper was questioned by the investigators. In the case of blue mold the complication is presented that the desirable internal effects were not obtained except with a combination of copper and vegetable oil.

It has been a question as to whether spray protection would not break down provided conditions favorable for disease development were prolonged. Under Georgia conditions in 1937, weather favorable for mold prevailed for more than 2 months. Before the end of this period, plants in sprayed beds reached a mild disease peak and recovery then took place promptly. The average interval between disease peak and recovery with sprayed plants was less than 4 days. Plants that have recovered from even a mild attack are highly resistant to blue mold and do not require any further protec tion regardless of weather. With prolonged favorable weather for the disease, instead of the situation becoming increasingly critical in sprayed beds, the mild disease cycle is completed, and after this the disease practically disappears. The process of protection by spraying seems to have some resemblance to vaccination.

VALUE OF THIN STANDS AND SPRAYING TO COVER BOTH LEAF SURFACES

It would appear logical to suppose that thin stands of plants and thorough coverages of both upper and lower leaf surfaces would be a material aid. The present results show, however, that beds with thick stands have been sprayed quite as successfully as beds with thin stands. Recommendations that growers attempt to cover both leaf surfaces are unnecessary, as this is impracticable with tobacco plants, and in all the work here reported, the exposed leaf surfaces only were coated with spray.

STIMULATION OF GROWTH AND INJURY CAUSED BY SPRAYING

During the course of extensive tests with many materials, definite stimulation was rarely observed prior to 1937. In that year in the eastern North Carolina and South Carolina districts, a number of sprayed beds showed growth stimulation. This was marked and one grower expressed the opinion that "the spray was a third better than any nitrate of soda he had ever seen." The occurrence of stimulation in definite localities suggests the possibility of copper deficiency in some of the soils.

Injury from the copper oxide-oil spray has occurred when the concentration of copper or oil was materially increased or when excessive applications were made. Injury is most likely to occur with very young, slow growing plants and causes the leaves to become characteristically cupped (fig. 5). Later, there is often a slight flecking and bronzing of lower leaves. Injury, unless extreme, is of little consequence and is corrected readily if the plants are sprayed lightly once or twice. Injury from excessive treatments usually requires several days to develop. When the copper oxide rate has been doubled, injury has not become pronounced until after the second application. Injury due to the accumulations of toxic amounts of copper in the soil has been suggested as a possibility. Most tobacco growers, however, move their seedbed locations each year so there

would be little opportunity for accumulations; furthermore, there has been no indication of toxic copper accumulation at either of two locations where spraying has been conducted continuously for 6 years. The fact that with other crops copper sprays in large amounts have been applied for many years and that toxic copper accumulation in the soil has never been reported would indicate that the moderate amounts of copper added to the soil by spraying are either eliminated or inactivated very readily.

FIGURE 5.—Spray injury produced by excessive applications of the copper oxide-oil spray on very young plants.

PRESENT STATUS OF SPRAYING IN RELATION TO BLUE MOLD CONTROL

A spray program has been developed and thoroughly tested. It has reduced blue mold damage to a low minimum consistently and has stood the test of severe disease conditions. The treatment is inexpensive [3] and introduces no complications, in that no changes in present plant-growing practices are involved. However, extensive research work on blue mold control is still in progress and improvements are confidently expected. While extensive studies have been conducted with the coppers and sulphurs particularly, the vegetable oils present many possibilities for further investigations. Particular attention is being given to the fungicidal value of different oils. Also, studies are being made on the value of materials such as xylol and paradichlorobenzene when added to the oil. The testing of fungicides, however, must be very thorough and repeated experiments are required before conclusions can be safely drawn; hence marked changes will probably not be made soon. A most important need is that blue mold control be developed as a part of a general program of plant-bed disease and insect control. For example, wild-

[3] CLAYTON, E. E., and GAINES, J. G. BLUE MOLD (DOWNY MILDEW) DISEASE OF TOBACCO. U. S. Dept. of Agr. Farm Bull. 1799, 16 pp., illus. 1938.

fire, blackfire, and flea beetle need to be considered. Some progress has been made along these lines. In Maryland, a combination of early sprays with bordeaux followed by the copper oxide-oil has given effective control in the plant bed of both wildfire and blue mold. In addition to spraying, work is being continued actively with other methods of blue mold control. The benzol gas-control method developed in Australia has outstanding merit.

It is conceivable that some soil treatment may be found that will render plants resistant to mold. While this seems unlikely, continued reports of developments along this line, together with the knowledge that induced plant resistance seems to be an established fact with the blue mold disease, point to the possibility. Genetic plant resistance of a high degree has as yet not been found, but much material remains to be examined. However, the suggestion that other *Nicotiana* species, which are practically immune, might be crossed with *N. tabacum* would seem to offer little promise. Considering that less than 10 years ago practically nothing was known regarding control of blue mold, it appears that not only is the grower now provided with a reasonably satisfactory control but there are distinct prospects for improvement in the future.

SUMMARY AND CONCLUSIONS

Bordeaux mixture and many other fungicides failed to effectively control blue mold.

Colloidal copper, copper-soap, and calcium monosulphide were all superior to bordeaux mixture, but not effective enough to be recommended.

A combination of cuprous oxide with emulsified cottonseed oil was distinctly superior to any of the preceding. The epidemic blue mold outbreak of 1937 offered an opportunity to thoroughly test the value of this method of control.

Beds were sprayed twice weekly and, in most instances, five to six applications were made prior to general mold outbreak. Many beds, however, received but three to four prior applications. Spraying was continued until the plants were set out or the disease became inactive. The maximum number of applications required under 1937 conditions was about 15. The maximum number actually applied was 23.

The results obtained lead to the following conclusions:

(1) The appearance of mold was usually but not always delayed by spraying.

(2) The development of the disease was greatly delayed.

(3) The severity of disease attack was greatly minimized. The maximum plant mortality in any sprayed bed was 16 percent, and under these same conditions plant losses in the unsprayed checks ranged up to 94 percent. In only two sprayed beds were more than 5 percent killed, and in the majority of beds no plants were killed, while in the majority of check beds from 20 to 50 percent of the plants were destroyed. The period of active disease development in sprayed beds was never more than 4 days, after which recovery was prompt and complete, and there was little transplanting delay. In the check beds, mold was active up to 3 weeks, and transplanting was delayed for 10 days to 5 weeks. Mold in sprayed beds represented no

field hazard, since field stands were uniformly good, even when the plants were set out at the time the disease was most active.

(4) Spraying was effective under severe disease conditions, and maximum gains were obtained when the need was greatest.

(5) On the average, from 2½ to 3½ acres of tobacco were set from each 100 square yards of sprayed tobacco bed during the normal transplanting season, while from unsprayed beds the transplantings ranged from 0 to 1⅓ acres.

While 1937 provided a severe test of blue mold control measures, this disease is too recent a problem to assume that all possible disease conditions have yet been encountered.

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